US005466131A

United States Patent [19]

Altham et al.

[11] Patent Number: 5,466,131

[45] Date of Patent: Nov. 14, 1995

[54] MULTIPLE-CHAMBER GEAR PUMP WITH HYDRAULICALLY CONNECTED CHAMBERS

[75] Inventors: **Tim J. Altham**, Castle Bytham, England; **Paul A. Johnson**, Vancouver, Wash.

[73] Assignee: **Micropump Corporation**, Vancouver, Wash.

[21] Appl. No.: **215,924**

[22] Filed: **Mar. 22, 1994**

[51] **Int. Cl.**^{6} **F04B 17/00**; F04B 21/00; F04B 23/04; F01C 1/24

[52] **U.S. Cl.** **417/420**; 417/199.1; 417/199.2; 417/435; 417/439; 417/522; 184/6.12; 418/200

[58] **Field of Search** 417/420, 199.1, 417/199.2, 435, 439, 522; 418/200, 102, 126; 184/6.12

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,382,042	8/1945	Etnyre	418/200
2,750,891	6/1956	Berry	418/200
2,931,303	5/1960	Dlugas	418/200
2,993,450	7/1961	Weigert	418/102
3,272,140	9/1968	Curry et al.	418/200
4,065,235	12/1977	Furlong et al.	
4,127,365	11/1978	Martin et al.	417/420
5,027,653	7/1991	Foran, Jr.	418/102
5,105,911	4/1992	Atkinson	184/6.12

FOREIGN PATENT DOCUMENTS

2729208	5/1979	Germany	418/200

OTHER PUBLICATIONS

Hobbs et al., "New Methods of Reducing Noise in External Gear Pumps," SAE Technical Paper Series No. 801005 (1980).

Micropump Brochure 001C, "A Guide to Pump and Motor Combinations Pump/Motor Selection Guide and Performance Parameters," (1993).

Primary Examiner—Richard A. Bertsch
Assistant Examiner—Ted Kim
Attorney, Agent, or Firm—Klarquist Sparkman Campbell Leigh & Whinston

[57] **ABSTRACT**

Pump heads comprising at least two gear-pump chambers are disclosed. Each chamber comprises a housing which defines a corresponding pump cavity. Each cavity contains a driving gear and at least one driven gear and has a separate inlet and outlet. The pump cavities are hydraulically interconnected by a fluid conduit allowing passage whenever the pump chambers are pumping a fluid so as to generate a higher pressure in one cavity relative to the other cavity, of the fluid from the higher-pressure cavity to the lower-pressure cavity sufficient to maintain hydraulic prime of both cavities.

7 Claims, 3 Drawing Sheets

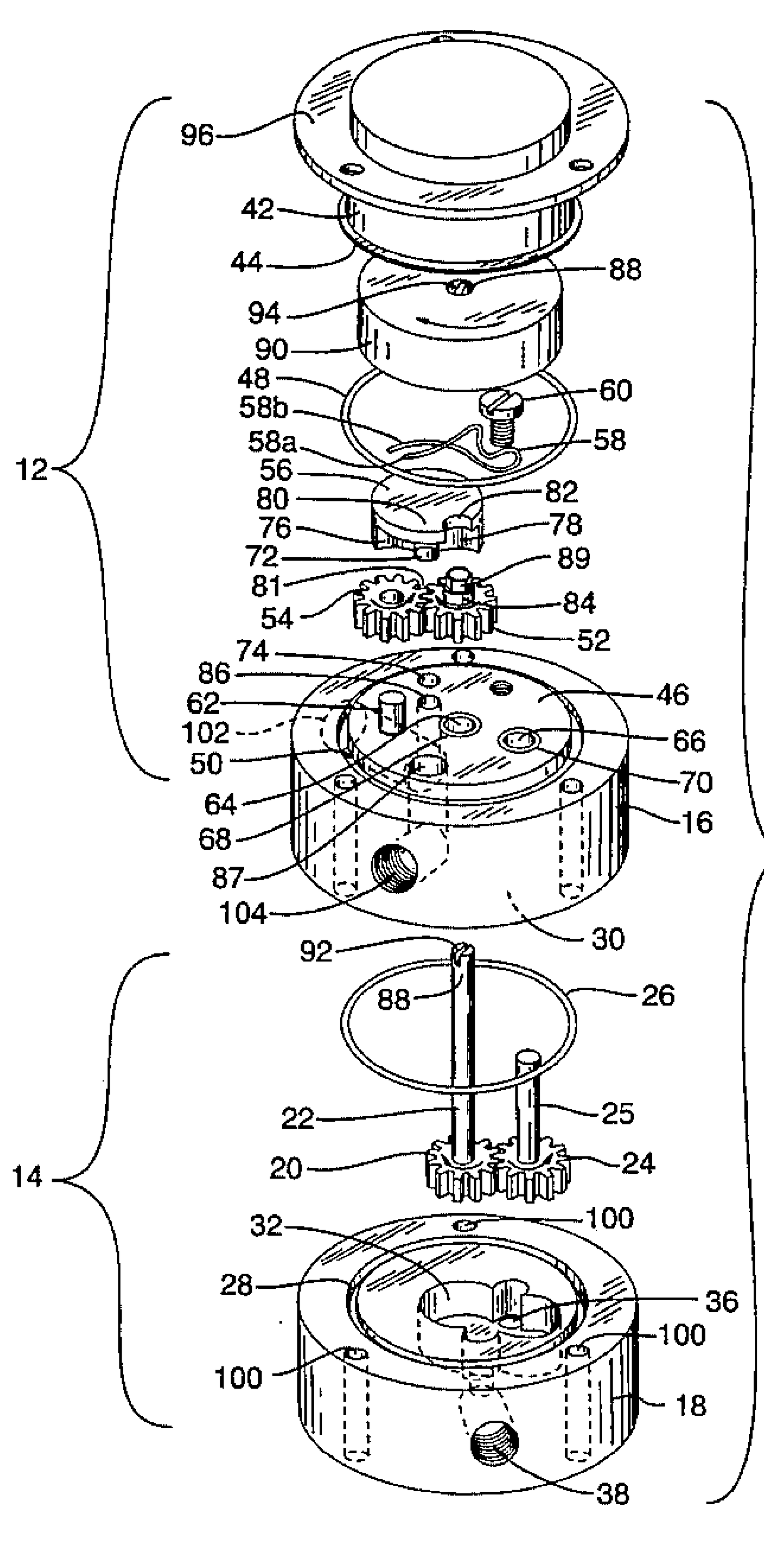


FIG. 1

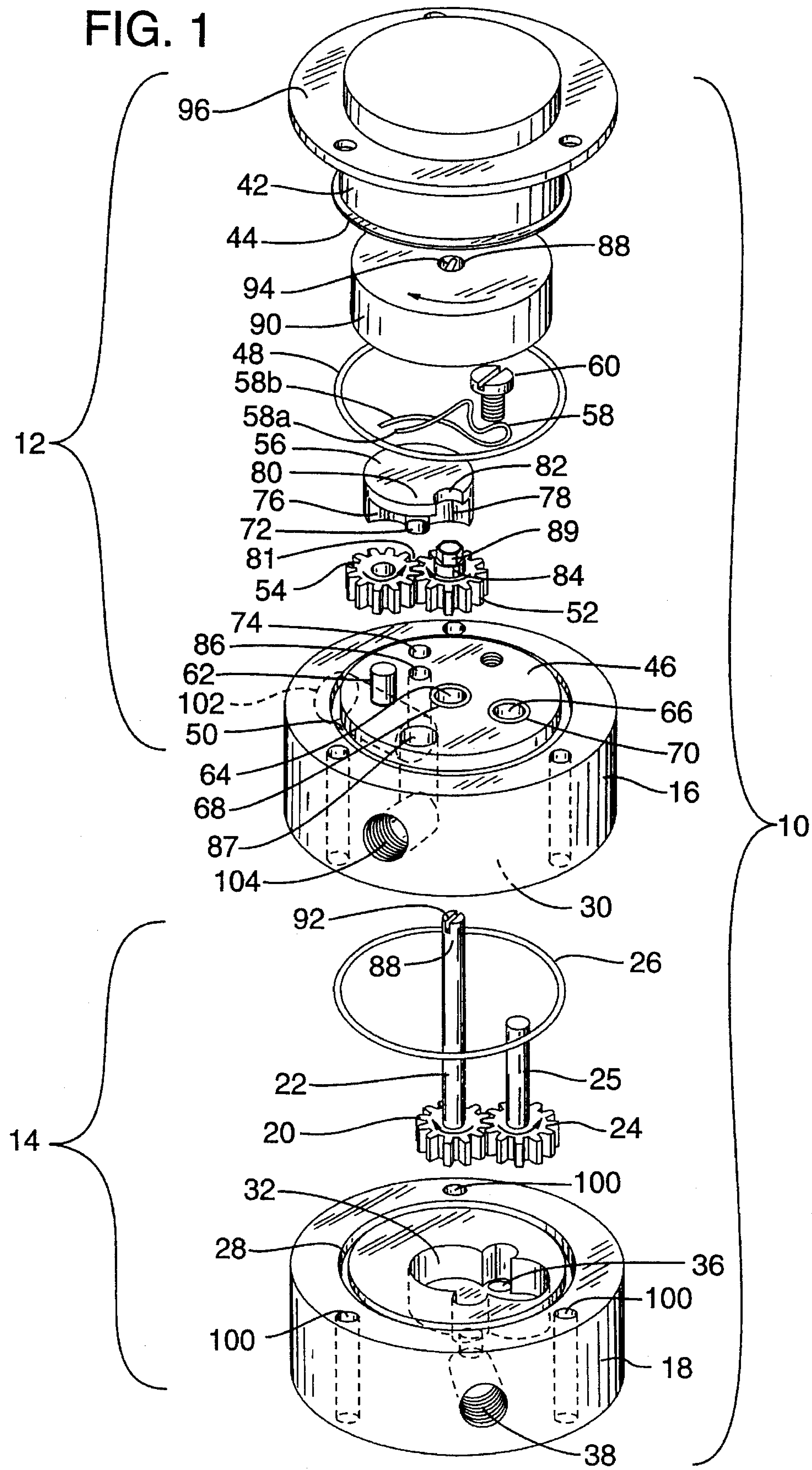

96
42
44
88
94
90
48
60
58b
58a
58
56
80
82
76
78
72
89
81
54
84
52
74
86
46
62
102
66
50
70
64
16
68
87
10
104
30
12
92
88
26
22
25
20
24
14
32
100
28
36
100
100
18
38

FIG. 2A

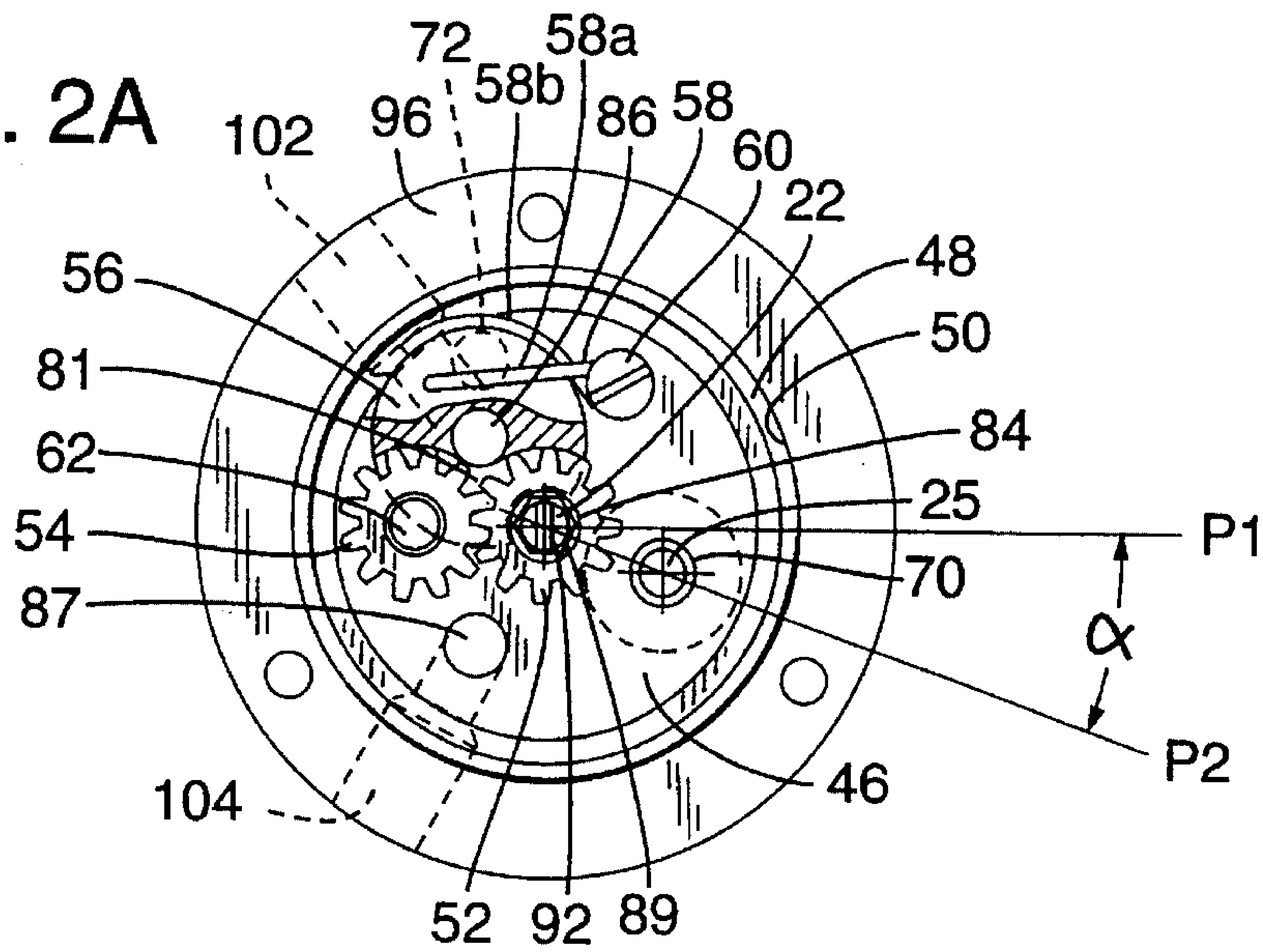


FIG. 2B

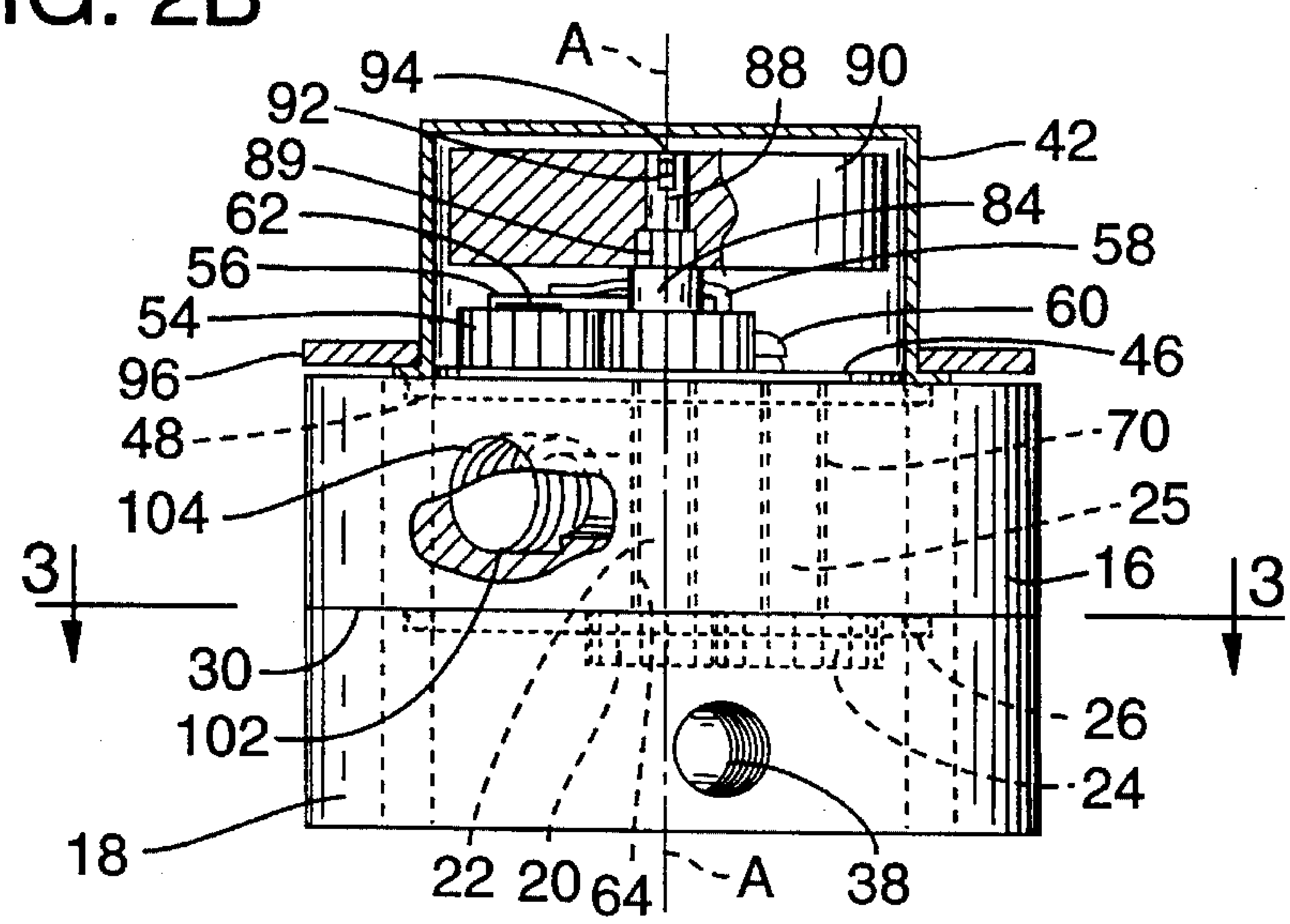


FIG. 3

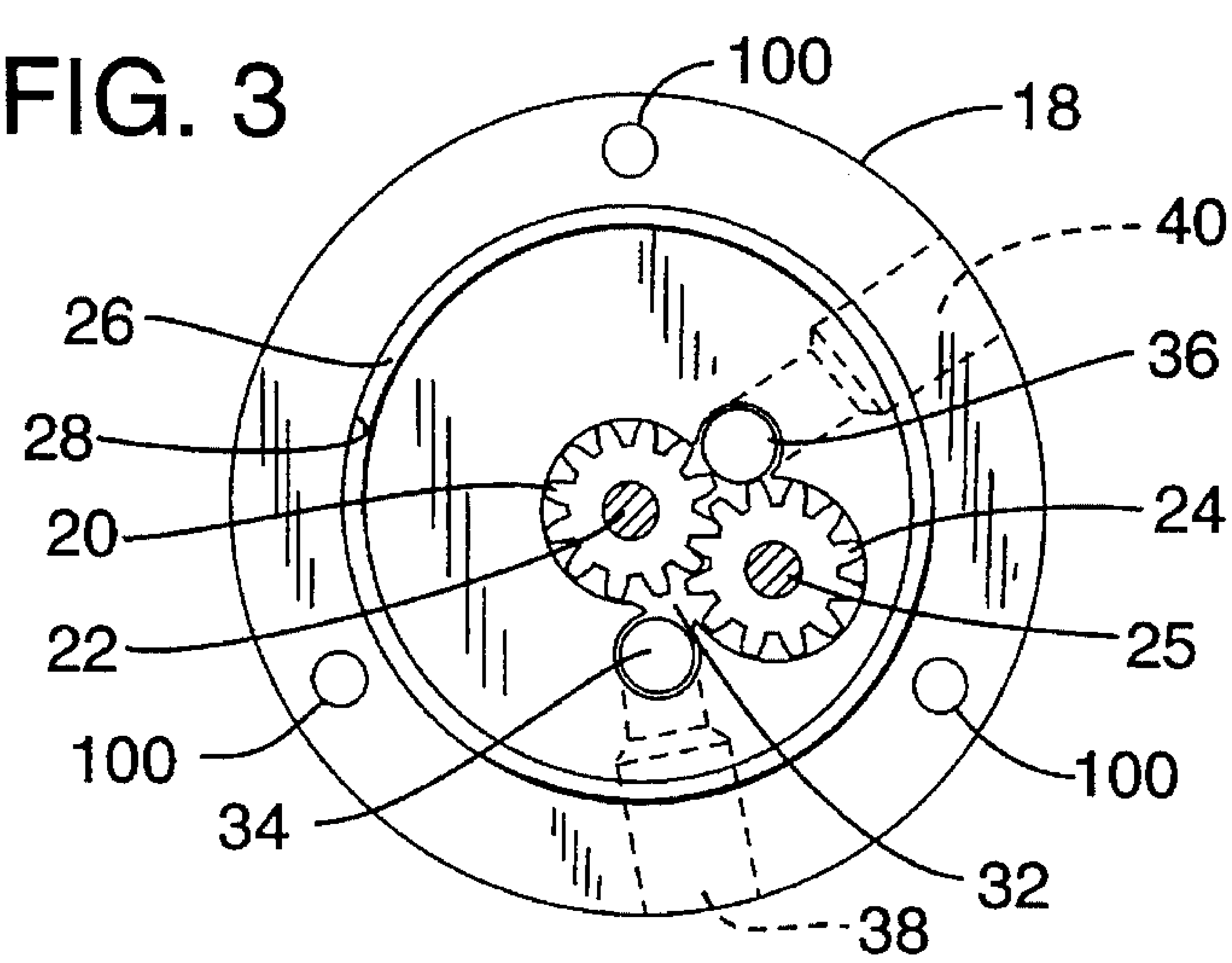
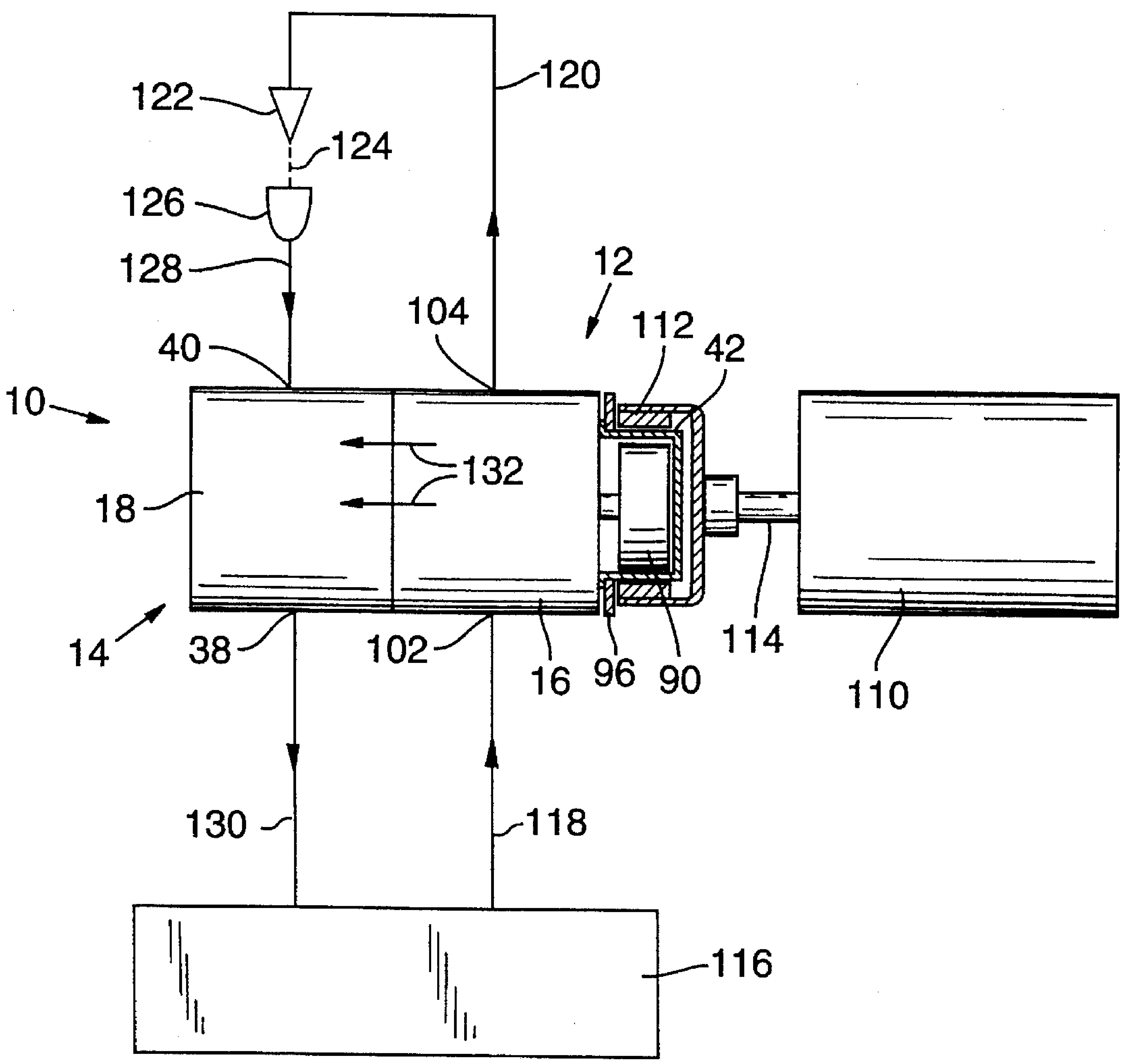


FIG. 4


120
122
124
126
128
12
104
112
42
40
10
132
18
14
38
102
16
96
90
114
110
130
118
116

MULTIPLE-CHAMBER GEAR PUMP WITH HYDRAULICALLY CONNECTED CHAMBERS

FIELD OF THE INVENTION

This invention pertains to hydraulic pumps, particularly gear pumps.

BACKGROUND OF THE INVENTION

Gear pumps as known in the art are particularly advantageous for pumping fluids while keeping the fluids isolated from the external environment. This benefit has been further enhanced by the advent of magnetically coupled drive mechanisms which have eliminated leak-prone hydraulic seals around drive shafts.

Gear pumps have been adapted for use in many applications, including applications requiring extremely accurate delivery of a liquid to a point of use. Such applications include, for example, delivery of liquids in medical instrumentation and delivery of liquid ink to continuous ink-jet printer heads.

Continuous ink-jet printing is rapidly becoming the method of choice for on-line application of text, such as on alphanumeric production code or bar code, to each of multiple similar objects moving continuously and rapidly in a series manner such as on a production line. For example, continuous ink-jet printing is frequently used for on-line application of production code to canned goods and medical products.

Continuous ink-jet printing requires an uninterrupted delivery of a continuous stream of liquid ink from a reservoir to a printer head. The printer head is typically stationary. The printer head controllably disintegrates the stream into a continuous series of discrete microdroplets of liquid ink. The trajectory of each microdroplet is instantaneously adjusted. Certain microdroplets are directed to deposit on preselected locations on each object being printed so as to form the desired printed pattern on the surface of the object. Alphanumeric print (and many other printable patterns such as bar code) are discontinuous; also, printing the same pattern on a series of objects moving past the printer head inherently requires temporary interruptions in the flow of ink from the printer head to the objects being printed. Hence, any microdroplets not destined to form part of the printed pattern on the surface of the object must be scavenged while in flight. Scavenging is usually effected by directing unused microdroplets to a "gutter." Ink collected in the gutter is returned, usually by pumping, to the ink reservoir used to supply ink to the printer head.

Ink collected in the gutter usually contains a substantial quantity of air bubbles. The presence of bubbles places unusual demands upon the type and features of the pump employed for returning the ink to the reservoir. In contrast, pumping ink from the reservoir to the printer head usually does not present a problem.

In certain conventional continuous ink-jet printing systems, gear pumps are used for both pumping tasks. Alternatively, in other conventional systems for continuous ink-jet printing, a gear pump is employed for delivering ink from the reservoir to the printing head and a venturi, actuated by a stream delivered by the gear pump, is used to withdraw collected ink from the gutter. In such a system, proper operation of the venturi requires a pumping capacity, substantially greater than what is required to provide ink to the

printing head, to create a sufficiently reduced pressure in the venturi.

Ongoing efforts to increase the efficiency and lower costs of equipment such as medical equipment and continuous ink-jet printing systems has stimulated interest in various hydraulic, including pump, improvements. For example, manufacturers have tried using only one pump motor coupled to two separate pump heads, thereby eliminating the cost of a separate pump motor for each pump head. Whereas efforts to date have been beneficial, further improvements are desired.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, a multiple-chamber pump head is provided for pumping a fluid. The pump head comprises at least two gear-pump chambers. Each of the first and second gear-pump chambers comprises a housing which defines a corresponding pump cavity. Each pump cavity contains a set of gears comprising a driving gear and at least one driven gear intermeshed with the driving gear. In a preferred embodiment, the driving gears are coaxially interconnected such as by a drive shaft, wherein the drive shaft extends from one pump cavity to another in a manner facilitating rotation of the drive shaft about its longitudinal axis. In each housing, each corresponding driven gear is rotatably mounted so as to mesh with the corresponding driving gear and thus undergo contrarotation relative to the corresponding driving gear whenever the drive shaft is rotated about its longitudinal axis. Each chamber also comprises an inlet and an outlet which allow fluid to enter and exit, respectively, the pump cavity.

In a preferred embodiment of the multiple-chamber pump head, the drive shaft is journaled in a bearing extending between the housings. The bearing allows passage of fluid therethrough from one pump cavity to the other, in particular from the pump, cavity normally having a higher internal pressure to the pump cavity normally having a lower internal pressure. This internal transfer of fluid from one pump cavity to another serves to maintain, inter alia, hydraulic prime of the pump cavity receiving such transferred fluid. Maintenance of prime in this manner is particularly advantageous whenever the pump cavity receiving fluid (i.e., the pump cavity having a lower internal pressure) is being used to deliver a liquid laden with a substantial amount of entrained air bubbles.

As an alternative or in addition to providing fluid passage through the bearing in which the drive shaft is journaled, it is also possible to provide a separate conduit permitting passage of fluid from the higher-pressure pump cavity to the lower-pressure pump cavity. The separate conduit can include one or more check valves, bleed valves, or other flow controllers as required.

A multiple-chamber pump head according to the present invention preferably comprises at least one each of two types of gear pumps known in the art, i.e., a "suction-shoe" pump, and a "cavity" pump. However, the present invention also comprehends multiple-chamber pump heads comprising two or more cavity pumps, suction-shoe pumps, or any combination of these and other types of gear pumps as defined herein. A combination of a suction-shoe pump and a cavity pump is especially preferred, particularly for use with continuous ink-jet printers, because performance of the cavity pump is relatively unperturbed by liquids containing substantial amounts of entrained air bubbles, such as present in-ink collected in a gutter, and the suction-shoe pump is particularly useful for maintaining an elevated internal pressure relative to the cavity pump. As discussed above, this elevated pressure facilitates passage of liquid from the suction-shoe pump to the cavity pump, which serves to maintain prime of the cavity pump.

Pump heads according to the present invention are powered by an electric motor or other suitable prime mover. Coupling the pump head to the prime mover is preferably via a magnetic coupling or analogous means that eliminates a need for the rotary seal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exploded view of a preferred embodiment of a pump head according to the present invention comprising a suction-shoe pump portion and a cavity-pump portion.

FIG. **2A** is an axial view of the embodiment of FIG. **1**, showing details of the suction-shoe pump portion.

FIG. **2B** is an elevational view of the embodiment of FIG. **1**, showing certain of its components as fully assembled.

FIG. **3** is a sectional view of the embodiment shown in FIG. **2B**, showing details of the cavity-pump portion.

FIG. **4** is a schematic view of a hydraulic circuit in which a multiple-chamber pump head according to the present invention can be used to supply liquid ink to a continuous ink-jet printer head.

DETAILED DESCRIPTION

As used herein, a "gear pump" encompasses any of various pumps utilizing at least two impellers or rotors (i.e., "gears") that are contrarotated relative to each other in a casing or housing, wherein one of said gears is a "driving" gear and the remaining gears in the pump are "driven" gears. Each gear has multiple teeth or lobes, oriented radially with respect to the axis of rotation of the gear, that interdigitate (i.e., "mesh") with corresponding teeth or lobes, respectively, in the mating gear. As the gears are contrarotated, fluid enters the spaces between the teeth or lobes of each gear and is transported by the gears to a discharge port. The term "gear pump" also encompasses any of various "internal-gear" pumps as known in the art.

A "pump head" as used herein is an assembly comprising at least one functional gear pump.

A "multiple-chamber pump head" as used herein is a pump head according to the present invention that comprises two or more chambers, wherein each chamber comprises a functional gear pump. The gear pumps in the chambers, which need not be of the same type, function cooperatively as described herein.

A "cavity pump" is a gear pump comprising at least two meshed contrarotatable gears situated in a gear cavity defined by a housing that encloses the meshed gears. During operation, fluid entering the cavity pump moves around the gear cavity in the spaces between the gear teeth or lobes to a discharge, or outlet, port of the gear cavity.

A "suction-shoe pump" is a variant of a cavity pump characterized by the employment of a "suction shoe" (as described herein and, e.g., in U.S. Pat. No. 4,127,365 to Martin et al., incorporated herein by reference). The suction shoe hydraulically isolates the inlet port of the pump from the outlet port sufficiently to eliminate the necessity for the cavity to conform closely to the profile of the meshed gears.

A representative embodiment of a multiple-chamber pump head **10** according to the present invention is illustrated as an exploded view in FIG. **1**. The components depicted in FIG. **1** are also shown in orthographic projection in FIGS. **2A**, **2B**, and **3**.

In FIG. **1**, the multiple-chamber pump head **10** comprises a "suction-shoe pump" portion **12** and a "cavity-pump" portion **14**. A separator body **16** serves to, inter alia, partition the suction-shoe pump portion **12** from the cavity-pump portion **14**.

The cavity-pump portion **14** comprises a cavity-pump body **18**, a first driving gear **20** coaxially affixed to a drive shaft **22**, a first driven gear **24** adapted to mesh with the first driving gear **20**, and a static fluid seal **26** (such as, but not limited to, an elastomeric O-ring as shown captured in an annular gland **28** in a surface of the cavity-pump body **18**). The first driven gear **24** is coaxially affixed to a shaft **25** to permit rotation of the first driven gear **24** about its axis. The cavity-pump body **18**, together with a first surface **30** of the separator body **16**, define a gear cavity **32** conforming to the profile and thickness of the meshed first driving gear **20** and first driven gear **24**.

As in conventional cavity pumps, the gear cavity **32** is shaped so as to allow the first driving gear **20** and first driven gear **24** to freely rotate about their axes in the gear cavity **32** with minimal clearance between the gears **20**, **24** and the walls of the gear cavity **32**. (As can be readily appreciated, the gears **20**, **24** rotate counter-currently relative to each other; i.e., they "contrarotate.") The gear cavity **32** also extends laterally outward to allow an inlet orifice **34** and an outlet orifice **36**, both defined by the cavity-pump body **18**, to open into the gear cavity **32**. The inlet orifice **34** hydraulically communicates with an inlet port **38**; and the outlet orifice **36** hydraulically communicates with an outlet port **40**. The inlet and outlet ports **38**, **40**, respectively, can be threaded or otherwise made capable of accommodating any of various suitable hydraulic fittings as required. The inlet and outlet ports **38**, **40** can be oriented in any convenient direction.

In the embodiment of FIGS. **1** and **2A–2B**, the suction-shoe pump portion **12** comprises a cylindrical cup **42** having a closed end and, on the opposing open end, a flange **44** adapted to engage against a second surface **46** of the separator body **16**. A seal **48** is used to facilitate sealing of the flange **44** to the separator body **16**. The seal **48** can be an elastomeric O-ring as shown, captured in an annular gland **50**, or can be any other analogous static seal appropriate for this application. Thus, the cup **42** and the second surface **46** of the separator body **16** together define a cavity in which are situated components of the suction-shoe pump, namely a second driving gear **52**, a second driven gear **54**, a suction shoe **56**, a bias **58** for the suction shoe **56**, and a screw **60** or analogous fastener for securing the bias **58** to the second surface **46**. The second driven gear **54** is coaxially mounted on a short shaft **62** affixed to and extending from the second surface **46** so as to allow the second driven gear **54** to axially rotate relative to the shaft **62**.

The shafts **22**, **25** extend through and are journaled in corresponding orifices **64**, **66** defined by the separator body **16**. The orifices **64**, **66** can be lined, if necessary or desired, with corresponding bushings **68**, **70**. (The bushings **68**, **70** could be eliminated by fabricating either the separator body **16** or the shafts **22**, **25**, or both, from materials, including composite materials, having suitably low coefficients of friction.) As shown in FIG. **2B**, the shaft **25** extends through the separator body **16** substantially to the second surface **46**. The shaft **22** also extends through the separator body **16** and projects from the second surface **46** to provide an axial mounting for the second driving gear **52**. As a result of the shafts **22**, **25** being journaled in the separator body **16** as shown in a manner allowing rotation about their respective axes, hydraulic communication occurs between the suction-shoe pump portion **12** and the cavity-pump portion **14**, as described in further detail below. Specifically, a hydraulic "leak" is established from the suction-shoe pump portion **12** (representing a "higher-pressure" pump portion) to the cavity-pump portion **14** (representing a "lower-pressure" pump portion).

The suction shoe **56** is similar to suction shoes found in conventional suction-shoe gear pumps, as disclosed, for example, in U.S. Pat. No. 4,127,365 to Martin et al., incorporated herein by reference. For proper positioning, the suction shoe **56** is provided with a pin **72** adapted to fit into an orifice **74** defined by the separator body **16** and opening onto the second surface **46**. The suction shoe **56** comprises a first arc-shaped edge **76** conforming with a portion of the circumference of the second driven gear **54**, and a second arc-shaped edge **78** conforming with a portion of the circumference of the second driving gear **52**, wherein both arc-shaped edges **76**, **78** define a recess on the underside of the suction shoe. The suction shoe **56** also comprises a top portion **80** adapted to extend partially over the mesh point **81** of the second driving and driven gears **52**, **54**, respectively. Finally, the suction shoe **56** comprises a semicircular cutout **82** adapted to conform to a cylindrical shoulder **84** on the second driving gear **52**.

The suction shoe **56** is preferably not rigidly mounted on the second surface **46**. Rather, referring to FIG. **1** for example, the bias **58** (secured to the second surface using the screw **60**) urges the suction shoe simultaneously toward the gears **52**, **54** and toward the second surface **46**, thereby minimizing clearance. In particular, one leg **58*a*** of the bias **58** wraps part way around the circumference of the suction shoe **56** to urge the shoe **56** toward the mesh point **81** of the gears **52**, **54**; another leg **58*b***, which is bent in a dog-leg, urges the shoe **56** toward the second surface **46**. Other bias means, in conformance with general principles of machine design, can alternatively be used as required to maintain proper positioning of the suction shoe **56** relative to the gears **52**, **54**.

When mounted to the second surface **46** with the bias **58** properly installed, the suction shoe **56** hydraulically isolates the immediate vicinity of an inlet orifice **86**, together with the mesh point **81**, from an outlet orifice **87** (both orifices being defined in the second surface **46** by the separator body **16**). The first and second arc-shaped edges **76**, **78**, respectively, and the top portion **80** of the suction shoe **56** engage the second driven and driving gears **54**, **52**, respectively, in a manner allowing the gears **52**, **54** to freely rotate about their respective axes with minimal clearance: (a) between the gears **52**, **54** and the arc-shaped edges **78**, **76**, (b) between the gears **52**, **54** and the top portion **80**, and (c) between the gears **52**, **54** and the second surface **46**.

During operation of the suction-shoe pump portion **12**, and as a result of the manner in which the suction shoe **56** is engaged against the gears **52**, **54** and the second surface **46**, an elevated pressure develops in the space defined by the cup **42** and the second surface **46** relative to the pressure at the inlet orifice **86**. This elevated pressure, typically substantially equal to the discharge pressure of the suction-shoe pump portion, urges the suction shoe **56** against the second surface **46** and against the gears **52**, **54**, thereby further enhancing the role of the suction shoe **56**.

This elevated pressure in the suction-shoe pump portion is also useful for facilitating fluid transfer from the suction-shoe pump portion **12** to the cavity-pump portion **14** sufficient to maintain hydraulic prime of the cavity-pump portion.

The second driving gear **52** is coaxially affixed to the shaft **22** extending through the orifice **64**. For ease of assembly, it is preferred that the second driving gear **52** be affixed indirectly to the shaft **22** in a manner such as the following: The shaft **22** extends beyond the second surface **46** a distance sufficient to allow the second driving gear **52** to be coaxially slipped onto the shaft **22** while leaving a terminus **88** of the shaft exposed. A male spline **89**, provided above and integral with the shoulder **84** of the second driving gear **52**, is adapted to engage a corresponding female receptacle (not shown) concentrically and coaxially provided in a driven magnet **90**, thereby allowing the driven magnet **90** to be coaxially mounted directly to the second driving gear. The terminus **88** of the shaft **22** is provided with a slot **92** adapted to engage a complementary key **94** provided in the driven magnet **90** to rotationally secure the driven magnet **90**, and thereby also the second driving gear **52**, to the shaft **22**. It will be appreciated that any of various other ways of affixing the second driving gear **52** to the shaft **22** can be employed, according to general principles of machine design.

The cup **42** can be secured to the separator body **16** by a securing ring **96** adapted to engage the flange **44** of the cup (FIG. **2B**) and urge the flange **44** against the seal **48**. Screws **98** extending through the securing ring **96**, the separator body **16**, and into corresponding threaded orifices **100** in the cavity-pump body **18** secure the entire assembly **10** together.

In the suction-shoe pump portion **12**, the inlet orifice **86** hydraulically communicates with a corresponding inlet port **102**; and the outlet orifice **87** hydraulically communicates with an outlet port **104**. The inlet and outlet ports **102**, **104**, respectively, can be threaded or otherwise made capable of accommodating any of various suitable hydraulic fittings as required. The inlet and outlet ports **102**, **104** can be oriented in any convenient direction.

A multiple-chamber pump head **10**, as shown in FIG. **1**, preferably (for most applications including use with continuous ink-jet printer heads) comprises driving gears **20**, **52** and driven gears **24**, **54** that are all the same diameter, thickness, and pitch. As with conventional gear pumps, the driving gear (e.g., gear **20**) and corresponding driven gear(s) (e.g., gear **24**) in any particular pump portion preferably have the same diameter, thickness, and pitch to ensure even hydraulic flow through the corresponding pump portion. But, other applications for a pump head according to the present invention may favor using, for example, gear sets (driving plus driven gears) in the suction-shoe pump portion **12** that have a different diameter, thickness, and/or pitch than the gears in the cavity-pump portion **14**. In some embodiments according to the present invention, such as an embodiment in which a pump portion comprises an "internal gear" configuration (as known in the art), the question of whether the driving and driven gear(s) in a pump portion have the same diameter is moot.

Across the thickness of the corresponding gears **20**, **24**, **52**, **54**, the gear teeth can be oriented parallel to the gear axis, as in ordinary spur gears, or can be helical or twisted to reduce pulsatility of flow.

The shaft **22**, serving as a "drive shaft" in the embodiment of FIG. **1**, need not be a single integral shaft. The shaft **22** can alternatively comprise several shaft elements connected together (not shown) so as to function as a single shaft or to otherwise cause driving gears **20**, **52** to synchronously rotate about their rotational axis.

To increase the pumping capacity of a given pump portion, the respective driving gear can be meshed, in the same pump portion, with more than one driven gear. In instances in which the subject pump portion is a suction-shoe pump employing more than one driven gear, each driven gear in the pump portion would be provided with its own suction shoe (which, as described above, overlaps the corresponding driven gear and a portion of the driving gear). Thus, a suction-shoe pump portion employing a driving gear and two driven gears would be provided with two suction shoes, one for each driven gear.

The gears **20**, **24**, **52**, **54** may be constructed of any suitable material to accommodate the fluid being propelled by the pump head **10**, as well as the temperature, pressure, and viscosity involved. All other components can be fabricated of any material suitable for their intended purpose, either metallic, plastic, composite, ceramic, or any future material yet to be invented or discovered. The driven magnet **90** can be made of any suitable magnetic material compatible with the fluid to be pumped.

As shown most clearly in FIGS. **2A** and **2B**, the shaft **22** is preferably aligned with the radial axis A of the multiple-chamber pump head **10**, thereby also placing the first and second driving gears on the radial axis A. In a manner typical of spur gears, the second driven gear **54** has a radial axis (not shown) that is parallel to A and laterally displaced from A in a plane **P1** a sufficient distance so as to allow the second driving and driven gears **52**, **54**, respectively, to mesh. The axis of the first driven gear **24** can be in the same plane **P1**. The axis of the first driven gear **24** can also be in another plane **P2** intersecting plane **P1** at A. The most preferred arrangement is to orient the plane **P2** relative to **P1** at an angle $\alpha=90°/T$ wherein T=number of teeth in each of the first driving and driven gears **20**, **24**, respectively. Such an angle α is sufficient to offset the pitch of the first driven gear **24** relative to the second driven gear **54** by about ½ pitch. Such an offset has been discovered to minimize pulsatile pressure fluctuations in fluid delivered by the dual-chamber pump head **10**.

Similarly, in instances (not shown) in which a pump portion comprises two driven gears, the axes of the driving gear and the first driven gear preferably reside in the plane **P1** and the axes of the driving gear and the second driven gear preferably reside in the plane **P2** with the angle e between **P1** and **P2** being the same as described above; i.e., $\alpha=90°/T$.

During operation of the pump head **10** shown in FIG. **1**, fluid passes from the suction-shoe pump portion **12** to the cavity-pump portion **14** by flowing between the shaft **22** (FIG. **1**) and its corresponding bearing and, if desired, between the shaft **25** and its corresponding bearing. (In a circuit as shown, for example, in FIG. **4**, such passage of fluid is indicated by arrows **132**.) Such fluid passage offers several benefits. First, and most importantly, the fluid passage maintains hydraulic prime of the cavity-pump portion **14**, even whenever the cavity pump portion **14** is pumping an air-laden liquid. Second, the fluid passage serves to purge debris and other possible wear products away from the shafts and their bearings. Third, it provides for effective heat dissipation from the shafts and their bearings. Fourth, it maintains a fresh fluid bearing in the space between the shaft surface and the bearing surface. (The last three benefits provide for superior wear characteristics.)

Thus, the embodiment shown in FIGS. **1–3** provides one way in which fluid can be passed from a "higher-pressure" pump portion (e.g., the suction-shoe pump portion **12**) to a "lower-pressure" pump portion (e.g., the cavity-pump portion **14**) sufficient to maintain hydraulic prime of the lower-pressure pump portion. That is, FIGS. **1–3** depict passage of the fluid along a passage that is coaxial with the drive shaft (and hence coaxial with the driving gears). Another way to achieve such coaxial passage is to provide a hollow drive shaft.

The fluid passage need not, however, be coaxial with the driving gears. It is also possible to provide a separate, non-coaxial "bleed" conduit (not shown) connecting the higher-pressure pump portion to the lower-pressure pump portion. The bleed conduit can be provided with one or more check valves, adjustable flow restrictors, pressure-relief valves and/or other flow and pressure controllers as required for a particular application.

Particularly (but not necessarily) in instances in which fluid passes from one pump portion to the other via a non-coaxial bleed conduit, it is not necessary that a drive shaft extend from one pump portion to the other pump portion (or that a "drive" shaft actually rotate, so long as the driving gears can be made to rotate).

As shown schematically in FIG. **4**, the multiple-chamber pump head **10** is preferably driven by an electric motor **110** magnetically coupled in a conventional manner to the magnet **90**. One way in which this is achieved is by mounting an annular driving magnet **112** to the armature **114** of the electric motor **110**, wherein the driving magnet **112** is positioned coaxially and circumferentially around the cup **42** so as to magnetically engage the magnet **90** inside the cup.

It is also possible to drive the driven magnet **90** using an "integrated motor" configuration as disclosed, for example, in U.S. Pat. Nos. 5,096,390 and 5,197,865, incorporated herein by reference.

Notwithstanding the foregoing, it will be understood that other types of prime movers (i.e., motors and the like) and other types of couplings (including direct couplings) between the prime mover and the pump head **10** can be employed. Alternative prime movers include, but are not limited to, hydraulic motors, mechanically actuated drive means, internal combustion engines, and any of various other prime movers capable of directly or indirectly imparting rotary motion to the driving gears. The magnetic coupling means described above can be replaced with any of various direct drives, pulley drives, gear drives, and analogous means according to the intended use and mechanical environment of the pump head **10** and generally understood principles of machine design. As is generally understood, using a magnetic coupling eliminates a need for passing a drive shaft from the external environment to inside the pump head **10**, which would require a rotary seal.

The multiple-chamber pump head according to the present invention can be employed, inter alia, in any of various applications in which a liquid is delivered through a hydraulic circuit by application of a different pressure differential to the liquid at at least two different locations in the circuit. In such schemes, a first pump chamber of the pump head imparts the first pressure differential at a first location in the circuit and a second pump chamber of the pump head imparts the second pressure differential at a second location in the circuit. The pressure differentials are characterized in that a higher pressure exists in the first pump chamber relative to the second pump chamber, thereby facilitating passage of a stream of the liquid from the first pump chamber to the second pump chamber sufficient to maintain hydraulic prime of the second pump chamber.

The multiple-chamber pump head **10** disclosed in FIGS. **1–3** is particularly advantageous for use in a hydraulic scheme for supplying a continuous ink-jet printing head as shown schematically in FIG. **4**. A reservoir **116** is provided for storing liquid ink. Ink is aspirated from the reservoir **116** through a conduit **118** coupled to the inlet port **102** of the suction-shoe pump portion **12**. The outlet port **104** of the suction-shoe pump portion **12** is connected via a conduit **120** to the printing head **122**. Droplets **124** not destined to be used for actual printing are scavenged in a gutter **126**. Ink collected in the gutter **126** is routed through a conduit **128** coupled to the inlet port **40** of the cavity-pump portion **14**. The outlet port **38** of the cavity-pump portion **14** is coupled to a conduit **130** which returns the scavenged ink to the reservoir **116**, thereby completing the circuit. Thus, the suction-shoe pump portion **12** imparts a first pressure differential to the circuit and the cavity-pump portion **14** imparts a second pressure differential to the circuit.

The scavenged ink that is returned from the gutter **126** to the reservoir **116** is typically laden with air bubbles. One would expect, from a knowledge of the prior art, that such entrained air would cause unacceptable fluctuations in delivery of ink through conduit **120**. But, in the pump head **10**, a greater pressure develops inside the suction-shoe pump portion **12** relative to the cavity-pump portion **14**. This pressure difference urges ink to pass from the suction-shoe pump portion **12** to the cavity-pump portion **14**. Such passage of ink serves to maintain hydraulic prime of the cavity-pump portion **14** (despite the presence of air therein) and prevents air from entering the suction-shoe pump portion **12** from the cavity-pump portion **14**. Also, the pressure gradient in the suction-shoe pump portion **12** between the inlet orifice **86** and the outlet orifice **87**, as described above, contributes to the maintenance of a strong positive pressure in the suction-shoe pump portion **12** relative to the cavity-pump portion.

When used with continuous ink-jet printing heads and other applications requiring similar hydraulic performance, the multiple-chamber pump head **10** also eliminates the need for a venturi "pump" conventionally used in such hydraulic schemes for aspirating ink from the gutter. Eliminating the venturi "pump" by using a pump head according to the present invention offers several advantages: First, the necessity to provide a large excess pumping capacity in the hydraulic circuit upstream of the venturi to enable the venturi to generate sufficient subatmospheric pressure in order to operate is eliminated. Second, the frequently experienced necessity to reduce the viscosity of the fluid being pumped (such as by adding a solvent) in order to satisfactorily operate a venturi is eliminated, thereby alleviating possibly adverse environmental and other ramifications associated with use of solvents.

Even with continuous ink-jet hydraulic schemes not employing a venturi (but rather employing two separate pumps), employing a pump head according to the present invention eliminates the conventional need to provide an excess supply of fluid to the pump downstream of the gutter (compared to the supply of fluid entering the pump providing ink to the printing head). Thus, employing a pump head according to the present invention for such an application can allow substantial simplification of the hydraulic flowpath associated with a continuous ink jet printer.

Even though the multiple-chamber pump head **10** is particularly suitable for applications requiring small size and accurate performance, such as for continuous ink-jet printing head applications, it will be understood that the size of the pump head **10** is not critical. The pump head **10** can be of any suitable size and can be used for any application in which its particular attributes, as disclosed above, would be beneficial.

According to a preferred embodiment, a pump head according to the present invention preferably comprises a suction-shoe pump portion and a cavity-pump portion. Other possible combinations according to the present invention, such as (but not limited to) all pump portions being suction-shoe pumps or cavity pumps, or any of various other gear-pump types, may be more suitable for other applications.

It is also comprehended that more than two pump portions can be incorporated into a multiple-chamber pump head according to the present invention, wherein each pump portion allows fluid to "leak" to the adjacent pump portion as described above.

It is also comprehended that the pump portions of a multiple-chamber pump head according to the present invention can be hydraulically connected in series or parallel in a hydraulic circuit. For example, the pump portions can be used in tandem to provide a "boosted" output.

In pump heads comprising more than two pump portions, it is preferable for the driving gears to be mounted coaxially on a single shaft or on shafts axially aligned and interconnected with each other so as to function as a single drive shaft. It is also possible for separate drive shafts in each pump portion to not be axially aligned while being mechanically interconnected (such as by using gears, pulleys and belts, or other analogous means) in a way causing the shafts to rotate synchronously as if they were mounted on a single shaft.

It will be apparent that a pump head according to the present invention can be incorporated into a manifold including some or all the various hydraulic conduits connected to the inlets and outlets of the pump head. Such manifolds are advantageous because they minimize conduit lengths and use of discrete hydraulic fittings and the like, thereby reducing the number of possible locations in the hydraulic circuit at which leaks can occur.

While the invention has been described in connection with a preferred embodiment and variations thereof, it will be understood that the invention is intended to comprehend all alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. A multiple-chamber pump head, comprising a first gear-pump chamber and a second gear-pump chamber,

(a) the first gear-pump chamber comprising
- a first housing defining a first pump cavity,
- a first driving gear situated within the first pump cavity and rotatable about a first axis that is fixed relative to the first housing,
- a first driven gear situated within the first pump cavity and rotatable about a second axis so as to mesh with the first driving gear and contrarotate about the second axis relative to the first driving gear whenever the first driving gear is rotating about the first axis,
- a first inlet allowing fluid to enter the first pump cavity so as to be propelled by the rotating first driving and driven gears through the first pump cavity, and
- a first outlet allowing fluid, propelled through the first pump cavity by the rotating meshed first driving and driven gears, to exit the first pump cavity;

(b) the second gear-pump chamber comprising a second housing defining a second pump cavity,

a second driving gear situated within the second pump cavity and axially connected to the first driving gear so as to be rotatable about the first axis synchronously with the first driving gear,

a second driven gear situated within the second pump cavity and rotatable about a third axis fixed relative to the second housing so as to mesh with the second driving gear and contrarotate relative to the second driving gear whenever the second driving gear is rotating about the first axis,

a second inlet allowing fluid to enter the second pump cavity so as to be propelled by the meshed second driving and driven gears through the second pump cavity, and

a second outlet allowing fluid, propelled through the second pump cavity by the rotating second driving and driven gears, to exit the second pump cavity; and

(c) the first and second pump cavities being interconnected by a fluid conduit coaxial with the first axis, the conduit allowing, whenever the first and second gear-pump chambers are pumping fluid so as to generate a higher pressure in the first pump cavity relative to the second pump cavity, fluid to pass from the first pump cavity to the second pump cavity so as to maintain hydraulic prime of both the first and second pump cavities.

2. A pumping apparatus, comprising:

(a) a prime mover; and

(b) a pump head as recited in claim **1** operably coupled to the prime mover so as to enable the prime mover to cause rotation of the first driving gear about the first axis.

3. A multiple-chamber pump head, comprising a first gear-pump chamber and a second gear-pump chamber,

(a) the first gear-pump chamber comprising

a first housing defining a first pump cavity,

a first driving gear situated within the first pump cavity and rotatable about a first axis that is fixed relative to the first housing,

a first driven gear situated within the first pump cavity and rotatable about a second axis fixed relative to the first housing so as to mesh with the first driving gear and contrarotate about the second axis relative to the first driving gear whenever the first driving gear is rotating about the first axis,

a first inlet allowing fluid to enter the first pump cavity so as to be propelled by the rotating first driving and driven gears through the first pump cavity, and

a first outlet allowing fluid, propelled through the first pump cavity by the rotating meshed first driving and driven gears, to exit the first pump cavity;

(b) the second gear-pump chamber comprising

a second housing defining a second pump cavity,

a second driving gear situated within the second pump cavity and rotatable about a third axis that is fixed relative to the second housing, the second driving gear being operably coupled to the first driving gear so as to cause the second driving gear to rotate about the third axis whenever the first driving gear is rotated about the first axis,

a second driven gear situated within the second pump cavity and rotatable about a fourth axis fixed relative to the second housing so as to mesh with the second driving gear and contrarotate relative to the second driving gear whenever the second driving gear is rotating about the third axis,

a second inlet allowing fluid to enter the second pump cavity so as to be propelled by the meshed second driving and driven gears through the second pump cavity, and

a second outlet allowing fluid, propelled through the second pump cavity by the rotating second driving and driven gears, to exit the second pump cavity; and

(c) the first and second pump cavities being hydraulically interconnected by a fluid conduit allowing, whenever the first and second gear-pump chambers are pumping fluid so as to generate a higher pressure in the first pump cavity relative to the second pump cavity, fluid to pass from the first pump cavity to the second pump cavity so as to maintain hydraulic prime of both the first and second pump cavities.

4. A pump head as recited in claim **3** wherein the first axis is colinear with the third axis.

5. A pump head as recited in claim **4** further comprising a drive shaft, coaxial with the first and third axes, extending from the first driving gear to the second driving gear and coupled to the first and second driving gears so as to synchronously rotate the first and second driving gears.

6. A pump head as recited in claim **5** wherein the drive shaft passes through the fluid conduit.

7. A pumping apparatus, comprising:

(a) a prime mover; and

(b) a pump head as recited in claim **3** operably coupled to the prime mover so as to enable the prime mover to cause rotation of the first driving gear about the first axis.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,466,131

DATED : November 14, 1995

INVENTOR(S) : ALTHAM ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Cover Page:

Item [56], third entry under the References Cited heading, "Dlugas" should be --Dlugos--.

Item [56], fifth entry under the References Cited heading, "9/1968" should be --9/1966--.

Column 2, line 37, "pump, cavity" should be --pump cavity--.

Column 2, line 67, "in-ink" should be --in ink--.

Column 7, line 45, "angle e" should be --angle α--.

Signed and Sealed this

Eighth Day of July, 1997

Bruce Lehman

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks